

Congestion Management

Accounting For Network Flows Phase 1 Milestone Report

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Agenda

- Background
- Goals
- Methods
 - ◆ Modeled Flow
 - ◆ Forecasted Flow
- Results
 - ◆ Modeled Flow
 - ◆ Forecasted Flow
- Enhanced Model
- Conclusion
- Recommendations

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- Presentation summarizes detailed report titled “***Accounting for Network Flows Paper***” available under the October 16, 2007, meeting materials section at:

<http://www.transmission.bpa.gov/business/CongestionManagement/default.cfm?page=materials>

- Research team included:
 - ◆ Todd Kochheiser
 - ◆ William Rogers
 - ◆ Keith Dalia
 - ◆ Kevin Johnson
- Project Manager: Scott Simons

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Background

- No operational methodology to reliably and accurately account for the sources of energy flow on the network
- Limited ability to proactively manage network congestion in the operating time horizon
- Transmission constraints have become a significant operational issue due in part to system load growth, industry deregulation, river-operation constraints, and the increased diversity of generation resources

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Background Continued:

- It has historically been considered difficult to calculate or predict network flows within the BPA Transmission System using transactional data because scheduling has typically been done system-to-system or at the net interchange level
- Transactions among geographically distributed systems do not identify the physical location of the energy being injected or withdrawn from the transmission network and instead only identify an aggregate system-to-system transaction
- Using system-to-system transactions in an operational network model can lead to misleading and inaccurate results

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Background Continued:

- As part of a regional Congestion Management initiative, this effort was commissioned to study solutions to these problems and develop a prototype model
- The model that was developed has shown some success in accounting for network flows, predicting future hour flows, and providing insight into potential sources of modeling error

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Background Continued:

- Network models currently in use for the calculation of Available Transfer Capability (ATC) are partially based on contracted use of the system via contracts or reservations
- The model presented is focused on the operating time horizon (real-time/current day) and uses declared uses of the system (transactions/schedules) and actual flow data

Goals

- Research an operational model to account for the sources of network flows
- Research the ability to predict flows several hours in advance
- Learn!

Methods

- Off-line analysis
- Historical Data: July 1st – August 31st
- Based on declared use (e-Tags / Schedules) as opposed to contracted use
- Only used data available to Transmission Services

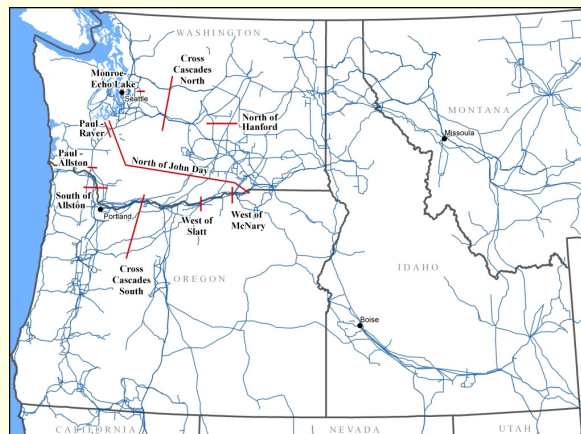
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Methods Continued:

- Analyzed ten major network flowgates



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Methods continued:

- Various operational data sources were used to enhance the model:
 - Customer load actual
 - Inadvertent Interchange & Interchange actuals
 - Federal Generation actuals
 - Power Transfer Distribution Factors

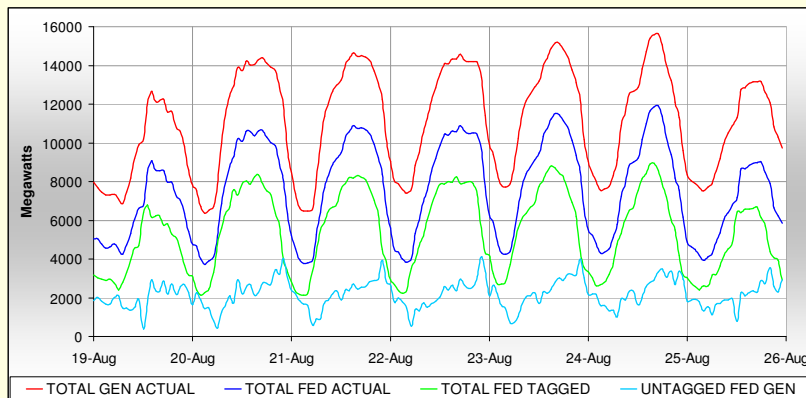
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Untagged Generation

- Not everything flowing on the network can be accounted for with a transaction
- As an example, the following chart shows untagged federal generation (difference between blue and green series)
- Untagged generation must be modeled using techniques other than tags such as customer load forecasts



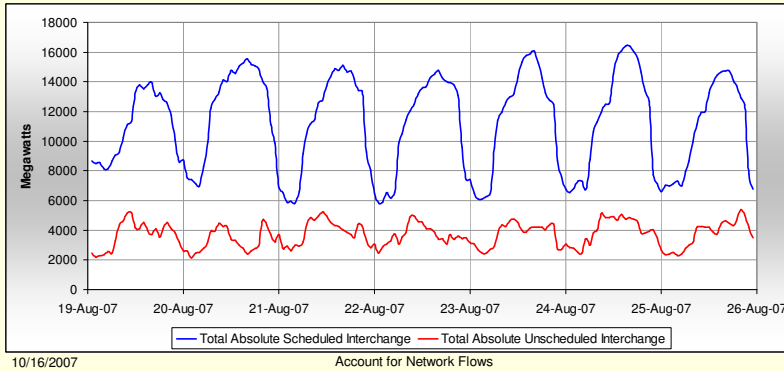
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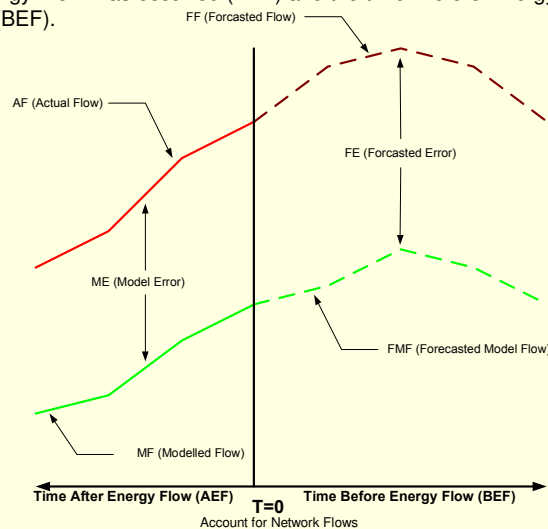
Unscheduled Interchange (inadvertent)

- In addition to untagged generation, there is a significant amount of unscheduled interchange (inadvertent or loop flow)
- For the week of August 19th the graph below shows the total absolute amount of scheduled (blue) and unscheduled (red) interchange between the BPA Balancing Authority Area and all adjacent Balancing Authority Areas (Average 3700MW Unscheduled)



Temporal Data

- The data associated with this study exists in two temporal domains: the time "After-Energy-Flow" has occurred (AEF) and the time "Before-Energy-Flow" has occurred (BEF).



Temporal Data Continued:

- Only AEF data - sometimes referred to as “actuals” - was considered for this study
- Using forecasted or BEF data would have introduced errors in the results that would have obscured the performance of the model and were generally avoided
- the performance of the model was assessed against Actual Flows (AF) on each flowgate

Modeled Flow

- The primary goal of the model is to calculate a Modeled Flow (MF) in the AEF temporal domain that most closely matches the Actual Flow (AF) by minimizing the Model Error (ME) for each flowgate in the study
- A secondary goal, and one that depends heavily on the quality of the calculated MF, is the ability to calculate a Forecasted Flow (FF) in the BEF temporal domain

Modeled Flow Continued:

■ Basic formula used can be summarized as:

Effects of Tags on flowgate
 +
 Effects of Customer Load on flowgate
 +
 Effects of Inadvertent Interchange on Flowgate

Modeled Flow – Basic Formula

$$MF = \sum_{n=1}^x Tag_n (PTDF_{POR_n} - PTDF_{POD_n}) + \sum_{n=1}^y Load_n (PTDF_{FCRTS} - PTDF_{Load_n}) + \sum_{n=1}^z Inadvertent_n (PTDF_{FCRTS} - PTDF_{Inadvertent_n})$$

Where:

Tag_n = The energy profile of the n^{th} e-Tag that had energy flow
 $PTDF_{POR_n}$ = PTDF value for the first BPAT POR on the n^{th} e-Tag
 $PTDF_{POD_n}$ = PTDF value for the last BPAT POD on the n^{th} e-Tag
 $Load_n$ = The energy profile of the n^{th} non-tagged internal customer loads served by the federal system
 $PTDF_{FCRTS}$ = PTDF value for the Federal Columbia River Transmission System (FCRTS) and BPAPower. May be statically or dynamically weighted (see PTDF section)
 $PTDF_{Load_n}$ = The PTDF value for the deemed bus representing the Point of Delivery (POD) of the n^{th} customer's load
 $Inadvertent_n$ = The energy profile of the inadvertent flow between BPAT and the n^{th} adjacent Balancing Authority
 $PTDF_{Inadvertent_n}$ = The PTDF value for the deemed bus representing the point of interchange with the n^{th} adjacent Balancing Authority

Power Transfer Distribution Factors (PTDF or PUF)

- An application was developed to programmatically produce bus level PTDF data for each flowgate in the study using the PowerWorld power flow application from a modified 2007 WECC base case using Grand Coulee as the reference (slack) bus
- As appropriate, system level Points of Receipt (POR) and system level Points of Delivery (POD), such as those used by e-Tags and schedules, were deemed to a specific bus
- **Note:** Deeming a bus for system level point introduces errors into the model. Using Injection Groups or multiple prorated bus level PTDF data would be preferable. This simple approach was chosen as the basis for this study as to more closely mimic the approach currently being utilized in the Short Term Market (STM) by BPAT

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PTDFs Continued:

- In the case of the Federal Columbia River Transmission System (FCRTS) and the Bonneville Power Administration's Power Service organization (BPAP), two approaches were used to develop a system level PTDF value that would more accurately account and correct for the locational-diversity of federal load and generation on the FCRTS
 1. A fixed dispatch of federal generation resources was assumed and a statically weighted federal PTDF value produced
 2. A dynamically weighted PTDF value was produced by utilizing hourly federal generation actuals.
- Most of this study used the dynamically weighted PTDF values

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Tags (e-Tags)

- E-Tags represent the primary source of transactional data in the model
- All implemented e-Tags for the period July 1st through August 31st were analyzed (Approx 65,000)
- PTDF values were selected for each e-Tag based on the first BPAT POR and last BPAT POD

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Load Data

- Load actuals for over 60 BPAP load following customers located within the BPAT system were provided by BPA's Agency Load Forecasting organization
- The customers' systems were deemed to a bus and the corresponding PTDF value used
- Each customer's load is served from the federal system by BPAP
- Proxy transactions were created from BPAP to each customer and integrated into the model

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Inadvertent and Loop Flow

- Accounting for this unscheduled/inadvertent flow was accomplished by retrieving both the scheduled and actual interchange values for every adjacent Balancing Authority Area and then calculating the associated inadvertent interchange
- Each adjacent Balancing Authority Area (16) was subsequently deemed to a bus and a proxy transaction created from the FCRTS to each adjacent Balancing Authority Area and integrated into the model

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Outages

- Outages, planned or otherwise, are recognized to effect PTDF values and consequently the accuracy of the model
- For this study, outages were not directly incorporated into the model

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Forecasted Network Flow

- The modeled flow (MF) and actual flow (AF) data sets were analyzed to test the potential ability to generate future-hour forecasted flows (FF)
- The formula and forecasting technique used are derived from control system theory
- The technique considers the values of the modeled flow for the current hour and prior two hours and the actual flow from the current hour
- These values are used to calculate network flows for following hours in a manner similar to a feed-forward control system

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Forecasted Flow Continued:

The formula used for one hour in the future ($t=+1$) is as follows:

$$FF_{t=+1} = AF_{t=0} + K_a(MF_{t=+1} - MF_{t=0}) - K_b(MF_{t=+1} - 2 * MF_{t=0} + MF_{t=-1})$$

Where:

$t = 0$	The time at which the most recent metered actual flows are available - it is the starting time from which the forecast will be generated.
$AF_{t=0}$	The most recently metered actual flow – the current real-time metered actual.
$MF_{t=0}$	The calculated modeled flow at time $t=0$
$MF_{t=+1}$	The calculated modeled flow one hour in the future from $t=0$
$MF_{t=-1}$	The calculated modeled flow one hour in the past from $t=0$
$FF_{t=+1}$	The forecasted flow one hour in the future
K_a and K_b	Tuning coefficients used to achieve optimal forecasted results.

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Forecasted Flow Continued:

For hours beyond $t=+1$, forecasted values are used as the basis for subsequent-hour forecasts. For two hours ($t=+2$) and three hours ($t=+3$) into the future, the formulae are as follows:

$$FF_{t=+2} = FF_{t=+1} + K_a(MF_{t=+2} - MF_{t=+1}) - K_b(MF_{t=+2} - 2 * MF_{t=+1} + MF_{t=0})$$

And

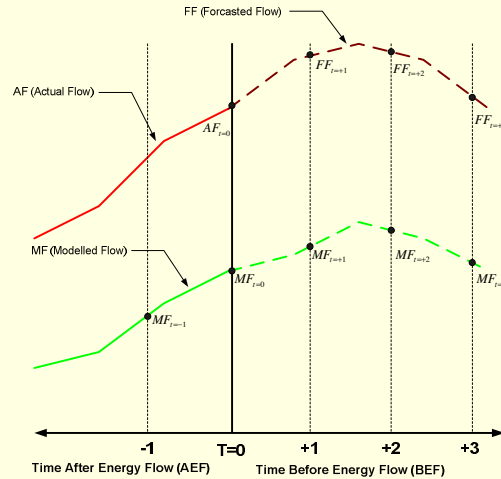
$$FF_{t=+3} = FF_{t=+2} + K_a(MF_{t=+3} - MF_{t=+2}) - K_b(MF_{t=+3} - 2 * MF_{t=+2} + MF_{t=+1})$$

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Forecasted Flow Continued:



$$FF_{t=+1} = AF_{t=0} + K_a(MF_{t=+1} - MF_{t=0}) - K_b(MF_{t=+1} - 2 * MF_{t=0} + MF_{t=-1})$$

$$FF_{t=+2} = FF_{t=+1} + K_a(MF_{t=+2} - MF_{t=+1}) - K_b(MF_{t=+2} - 2 * MF_{t=+1} + MF_{t=0})$$

$$FF_{t=+3} = FF_{t=+2} + K_a(MF_{t=+3} - MF_{t=+2}) - K_b(MF_{t=+3} - 2 * MF_{t=+2} + MF_{t=+1})$$

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Forecasted Flow Continued

- **Ka** and **Kb** are the tuning coefficients used to achieve an optimal feed-forward control loop
- By varying **Ka** and **Kb**, the tendency to overshoot or undershoot on forecasted values can be adjusted for optimal results
- In order to arrive at optimal values for **Ka** and **Kb**, an algorithm examines historical data and calculates which values would have been most successful over a recent historical timeframe and then uses those coefficients for future hour forecasting.
- The algorithm reevaluates the optimal coefficients on a periodic basis

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Results

The model was analyzed using a variety of datasets:

1. Electronic Tags (both normal and dynamic) and Dynamic PTDF's for the federal system (e.g. FCRTS or BPAPower). This dataset was used to assess the impact of ONLY using tags
2. In addition to the data used in dataset #1, load following customer data was added to the model.
3. In addition to the data used in dataset #2, inadvertent interchange was added to the model and **represents the most complete set of operational data available**
4. This dataset was created to assess the impact of using static PTDFs instead of dynamic PTDFs. This is the only variance from dataset #3
5. As dynamic tagging has become more common, this dataset was created to assess the impact of excluding dynamic tags. This is the only variance from dataset #3

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Datasets Summary

Dataset	e-Tags	Dynamic e-Tags	Dynamic PTDFs	Customer Loads	Inadvertent Interchange	Static PTDFs
#1	✓	✓	✓			
#2	✓	✓	✓	✓		
#3	✓	✓	✓	✓	✓	
#4	✓	✓		✓	✓	✓
#5	✓		✓	✓	✓	

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Statistic Produced

- For each dataset, statistics were produced for July 1st through August 31st
- Statistics were also produced for all hours and just heavy load hours (HE07-HE22)

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Calculated Statistics

Correlation Factor:	A number between -1.0 and 1.0 that indicates the general "fit" of two sets of data. For our purposes, we are comparing the Actual Flow (AF) with the Modeled Flow (MF). A value of 1.0 is ideal. [CORREL(AF,MF)]
Mean Error:	The mean of the difference between the Actual Flow (AF) and the Modeled Flow (MF) – essentially the mean of the observed Model Error (ME). [AVERAGE(ME)]
Standard Deviation of Error:	The standard deviation of the difference between the Actual Flow (AF) and the Modeled Flow (MF). [STDEV(ME)]
Mean of Abs. Error	The mean of the absolute difference between the Actual Flow (AF) and the Modeled Flow (MF). [AVERAGE (ME)]
Standard Deviation of Abs. Error:	The standard deviation of the absolute difference between the Actual Flow (AF) and the Modeled Flow (MF). [STDEV(ME)]
% Relative Error (Actual):	The error, as a percent, of the mean absolute error relative to the mean absolute Actual Flow. [AVERAGE(ME)/AVERAGE(AF)]
% Relative Error (OTC):	The error, as a percent, of the mean absolute error relative to the mean absolute Operating Transfer Capability (OTC). [AVERAGE(ME)/AVERAGE(OTC)]
Mean of Actual Flow:	The mean of the Actual Flow (AF). [AVERAGE(AF)]
Mean of OTC:	The mean of the Operating Transfer Capability (OTC). [AVERAGE(OTC)]

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Modeled Flow Summary Statistics Dataset #3

Modeled Network Flow Results									
July 1 - August 31 Heavy Load Hours	CORRELATION	MEAN ERROR	STDEV of ERROR	MEAN ABS ERROR	STDEV of ABS ERROR	% RELATIVE ERROR (ACTUAL)	% RELATIVE ERROR (OTC)	MEAN ACTUAL	MEAN OTC
Model Dataset #3 Tags / Loads / Inadv / Dynamic PTDFs									
Cross Cascades North	0.946	271.1	214.2	302.9	166.3	8.18%	2.91%	3702.6	10411.6
Cross Cascades South	0.787	63.7	253.9	212.6	152.6	7.13%	2.83%	2982.8	7511.3
Monroe-Echo Lake	0.951	-267.8	100.1	268.0	99.6	30.68%	16.96%	866.7	1580.4
North of Hanford	0.987	81.3	171.0	155.5	107.9	6.55%	3.54%	2351.2	4396.7
North of John Day	0.985	411.9	215.3	416.9	205.4	8.72%	5.51%	4780.8	7571.7
Paul-Allston	0.976	-100.1	68.0	105.1	60.0	6.47%	3.49%	1624.3	3011.5
Raver-Paul	0.974	290.1	52.4	290.1	52.4	48.30%	18.36%	597.8	1580.4
South of Allston	0.941	112.0	163.2	164.4	110.0	9.24%	6.11%	1779.4	2691.2
West of McNary	0.771	26.6	137.7	110.8	85.9	7.08%	3.94%	1563.9	2808.2
West of Slatt	0.947	297.0	132.0	298.0	129.6	11.21%	7.27%	2657.7	4099.9

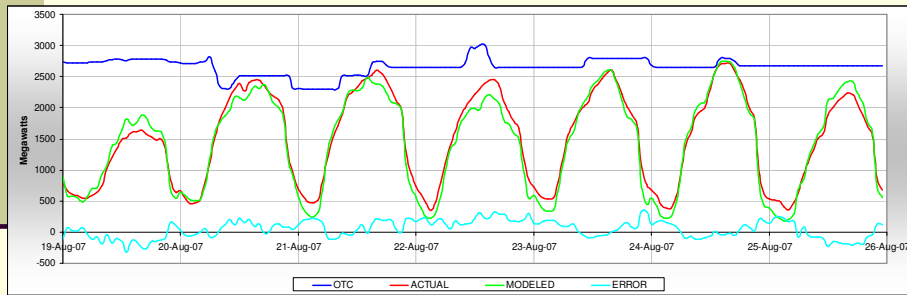
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Modeled Flow – Example Chart

■ South of Allston – Week of August 19th



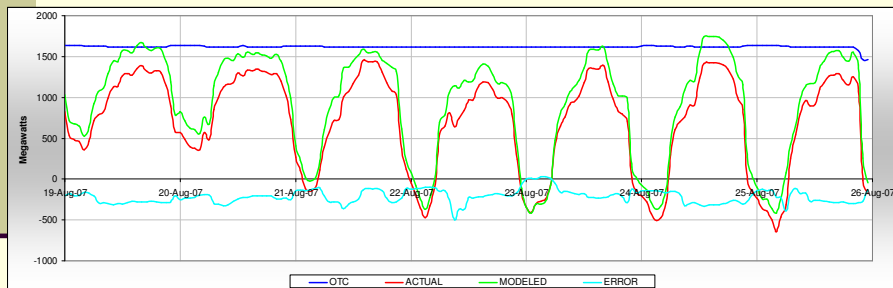
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Modeled Flow – Example Chart

■ Monroe-Echo Lake – Week of August 19th



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Forecasted Network Flow Statistics Dataset #3

- Unlike the model flow results, the statistics represent *all hours of the day* for the period July 1st through August 31st
- Statistics are available for T=+1, T=+2, and T=+3 but only T=+2 are shown

Forecasted Network Flow Results (T=+2)									
July 1 - August 31 All Hours (T=+2)	CORRELATION	MEAN ERROR	STDEV of ERROR	MEAN ABS ERROR	STDEV of ABS ERROR	% RELATIVE ERROR (ACTUAL)	% RELATIVE ERROR (OTC)	MEAN ACTUAL	MEAN OTC
Model Dataset #3 Tags / Loads / Inadv / Dynamic PTFs									
Cross Cascades North	0.976	2.4	181.5	127.3	129.3	3.79%	1.20%	3362.0	10624.4
Cross Cascades South	0.882	2.0	168.1	122.0	115.6	4.27%	1.61%	2855.5	7583.6
Monroe-Echo Lake	0.991	0.6	58.7	41.8	41.1	5.47%	2.64%	715.0	1582.2
North of Hanford	0.992	0.6	168.8	124.7	113.8	6.71%	2.85%	1700.3	4380.2
North of John Day	0.992	1.7	204.7	153.8	135.0	3.81%	2.02%	4036.1	7611.4
Paul-Allston	0.990	0.2	59.1	44.1	39.3	3.12%	1.51%	1414.4	2912.2
Raver-Paul	0.985	0.1	52.0	39.2	34.1	7.68%	2.48%	484.4	1582.2
South of Allston	0.983	0.6	112.4	85.0	73.5	5.77%	3.17%	1472.0	2681.1
West of McNary	0.958	0.4	79.0	52.5	59.0	3.66%	1.87%	1436.5	2805.8
West of Slatt	0.980	0.9	107.2	71.3	80.0	2.96%	1.74%	2408.6	4099.9

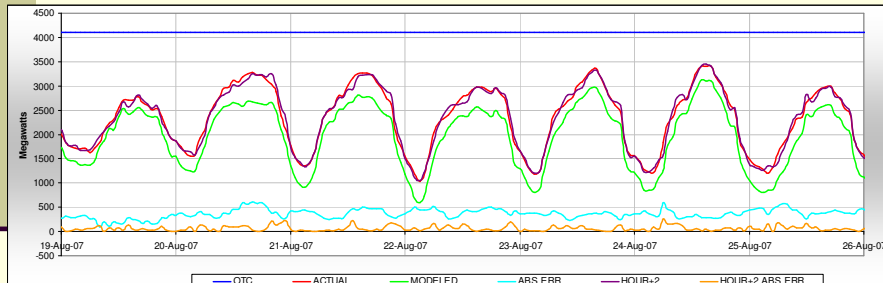
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Forecasted Flow – Example Chart

- West of Slatt – Week of August 19th



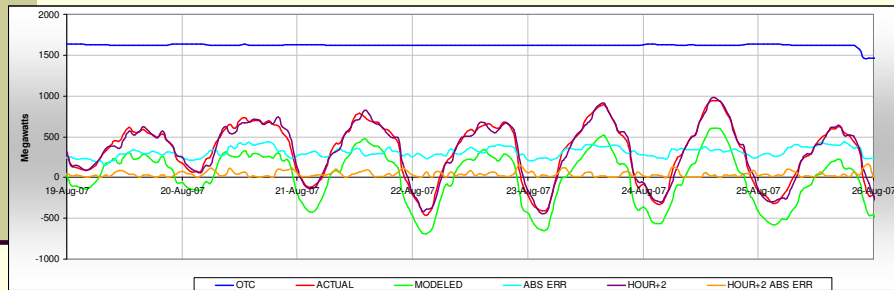
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Forecasted Flow – Example Chart

■ Raver-Paul – Week of August 19th



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Enhanced Model

- An enhancement to the basic modeled flow function was experimented with and provided good results
- It involves using the actual interchange values for an adjacent Balancing Authority as a method of allocating transactional data to the proper location
- Those adjacent Balancing Authorities with numerous interchanges in geographically distributed locations of the network and on different sides of major flowgates produce the best results
- While this method did provide impressive results for some flowgates, not all flowgates showed an improvement and more analysis is required
- Further, as this method makes heavy use of interchange actual data it may be difficult to integrate it into an operational model without accurate interchange forecasts or a scheduling methodology that provided more resolution at the interchange level

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Enhanced Model Results

- Using dataset #3 the enhanced Modeled Flow algorithm was applied to two adjacent Balancing Authorities:
 1. Puget Sound Energy (PSEI)
 2. PacifiCorp-West (PACW).
- The **Monroe-Echo Lake** and **West of Slatt** flowgates were analyzed

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Enhanced Model Results Continued:

July 1 - August 31 Heavy Load Hours			July 1 - August 31 Heavy Load Hours		
Monroe-Echo Lake	Base	Enhanced	West of Slatt	Base	Enhanced
CORRELATION	0.951	0.976	CORRELATION	0.947	0.961
MEAN ERROR	-267.8	-0.5	MEAN ERROR	297.0	-3.5
STDEV of ERROR	100.1	66.8	STDEV of ERROR	132.0	113.7
MEAN ABS ERROR	268.0	51.2	MEAN ABS ERROR	298.0	81.7
STDEV of ABS ERROR	99.6	43.0	STDEV of ABS ERROR	129.6	79.0
% RELATIVE ERROR (ACTUAL)	30.68%	5.86%	% RELATIVE ERROR (ACTUAL)	11.21%	3.08%
% RELATIVE ERROR (OTC)	16.96%	3.24%	% RELATIVE ERROR (OTC)	7.27%	1.99%
MEAN ACTUAL	866.7		MEAN ACTUAL	2657.7	
MEAN OTC	1580.4		MEAN OTC	4099.9	

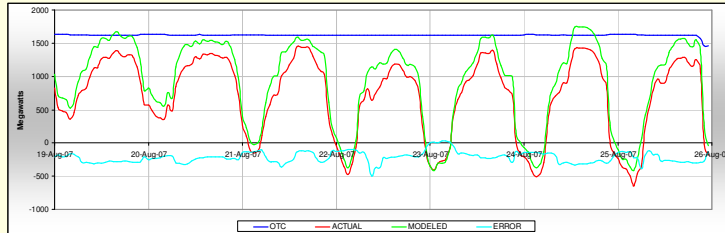
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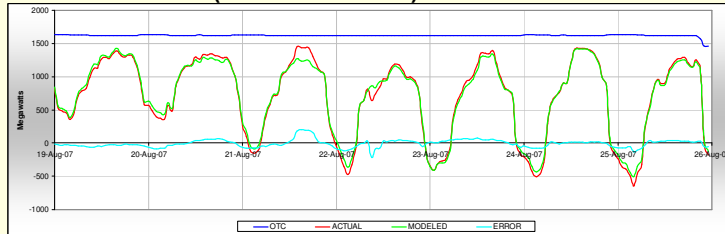
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Enhanced Model Results Continued

Monroe-Echo Lake (Base Model)



Monroe-Echo Lake (Enhanced Model)



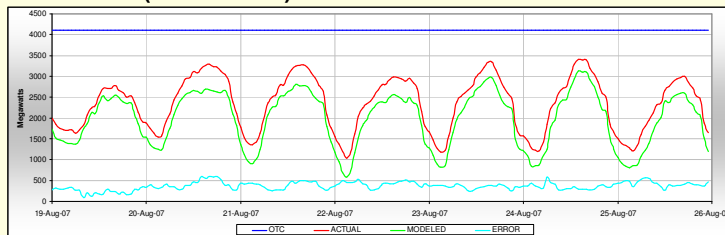
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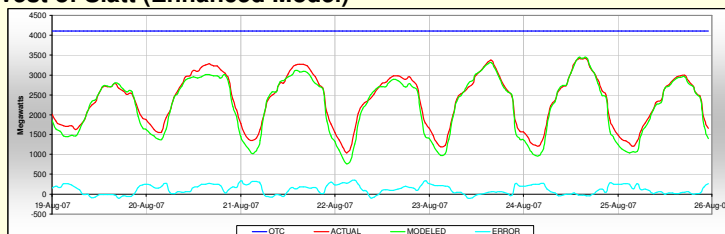
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Enhanced Model Results Continued

West of Slatt (Base Model)



West of Slatt (Enhanced Model)



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Conclusion

- Results are promising and could eventually be the basis for:
 - Early warning system (headlights)
 - Network curtailment calculators
 - Hourly ATC methodology
 - Realtime network scheduling controls
- Including network load actuals and inadvertent flow data generally improved the performance of the model
- Some problems to be resolved:
 - Deeming errors and granularity
 - PTDF accuracy and use of cut case versus full case
 - Mid-Columbia (a.k.a. MIDC or MIDCRemote)
 - Effect of system-to-system scheduling
 - Effect of outages

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Recommendations

- More research!
 - Modeling
 - Deeming
 - Forecasting
 - Techniques to mitigate system-to-system scheduling
 - Data quality analysis
- Development of a reference model based on only actuals (no transactional data). This will provide the following benefits:
 - Fine-tune deeming
 - Analyze effect of PTDF base cases on results
 - Analyze effect of outages on results
 - Provide a reference to compare models and forecasting techniques against
- Analysis of time-differentiated (bi-temporal) datasets to simulate the performance of the models using forecasted/estimated data.

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Thank You

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